A Performance and Closure Evaluation Approach for Pump-and-Treat Systems – 15132

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ABSTRACT

Pump-and-Treat (P&T) technology has been widely applied for groundwater remediation across many types of sites and for multiple types of contaminants. Decisions regarding major changes in the remediation approach are an important element of environmental remediation management for a site using P&T. An evaluation approach that includes an assessment of P&T system performance is under development to facilitate remediation decisions for P&T systems. The approach provides information on technical data and analyses that can be used to support remediation decisions. The document is organized to help decision makers distinguish between several categories of decision outcomes. These outcomes include 1) Initiate Remedy Closure, 2) Transition P&T to Monitored Natural Attenuation, 3) Continue P&T, 4) Supplement P&T with Another Treatment Technology, 5) Transition from P&T to Another Treatment Remedy, and 6) Transition P&T to an Alternative Closure or Contamination Management Approach. Key triggers that support selection of the appropriate outcome are provided, along with a description of suitable supporting data needed to formulate the technical basis for a remediation decision.

INTRODUCTION

Groundwater remediation with the pump and treat (P&T) technology has been applied for numerous sites. P&T was the most common groundwater remedy prior to 1997, and in 2001 was listed as a remedy in 20% of groundwater decision documents [1]. A recent National Research Council study examined groundwater remediation for complex contaminated sites and concluded that evaluating remedy performance and the potential need for transition to alternative approaches may be beneficial at these sites [2]. Review of remedy performance and consideration of remedy closure or transition are also consistent with the U.S. Environmental Protection Agency's (EPA) Groundwater Road Map [3]. Thus, there is a need to provide a structured approach for assessing P&T performance to support a decision to optimize, transition, or close a P&T remedy.

P&T is applied for hydraulic manipulation of the aquifer for the purpose of changing the hydraulic gradient and capturing contaminated groundwater. This type of manipulation may be used to help contain a source or plume even though overall contaminant mass reduction within the source or plume is not efficient. Hydraulic manipulation includes the effect of groundwater extraction and, in some cases, injection/infiltration of treated water on the hydraulic gradients in the aquifer.

The process of extracting contaminated groundwater from a saturated zone (i.e., aquifer) in the subsurface via pumping wells is a core component of P&T. This process involves fluid flow through the porous media of the subsurface and mass transfer processes related to the nature of the porous media, phases present, contaminant properties, and flow regimes derived from the geological materials of the subsurface. The typical intent of groundwater extraction is to bring contaminants to the surface for aboveground treatment. Aboveground treatment processes are very versatile and designed with well-understood process engineering methods and treatment principles, and are not addressed further in this P&T assessment approach. A groundwater monitoring program provides information for assessing the performance of the P&T system, in particular by providing information about contamination at locations downgradient from the P&T system. Data obtained from hydraulic and contaminant monitoring of the P&T extraction wells themselves are important. Monitoring well information is also important to augment P&T system data for additional spatial coverage of the plume or source, in particular for assessing the portion of the plume downgradient of the P&T system. Guidance for design and optimization of P&T using this information is available (e.g., [4, 5, 6, 7]), but specific technical guidance for assessing P&T performance with respect to closure or transition to other remedies is not.

An evaluation approach is under development to facilitate remediation decisions for P&T systems. The approach provides information on technical data and analyses that can be used to support remediation decisions. The core elements of the approach are discussed below.

DISCUSSION

Three categories of P&T implementation, based on the functional purpose or remedial goals of the system, were considered in developing criteria as guidance for evaluation of P&T performance and closure. These categories include 1) P&T for source control, 2) P&T for plume reduction, and 3) P&T for plume containment. Source control applications focus on eliminating or minimizing the flux of contaminants out of the contaminant source area and can be an important component of a remedy to diminish a downgradient plume (Figure 1). In addition to source control, P&T is commonly applied to contain a plume to protect downgradient receptors (Figure 2). P&T is also sometimes deployed for plume reduction, where the goal is to collapse a plume and remove contaminant mass (Figure 3). These categories of P&T implementation need to be considered when collecting and analyzing data for describing P&T performance. While not explicitly described herein, the technical guidance under development includes information to tailor the approach for each type of P&T category.

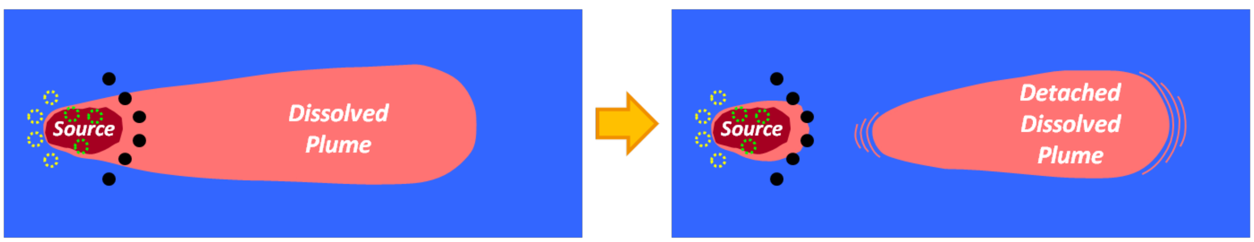

Figure 1. *Conceptual application of P&T for source control, showing (at right) the intended outcome of cutting off the source from the main dissolved phase plume. The detached plume would need to be treated by natural attenuation or an active remediation technology. Solid points denote an example configuration of extraction wells just downgradient from the source area. Dashed circles indicate additional options of extraction wells within the source area (for source removal and control) and upgradient of the source area (for hydraulic control to facilitate source control).*

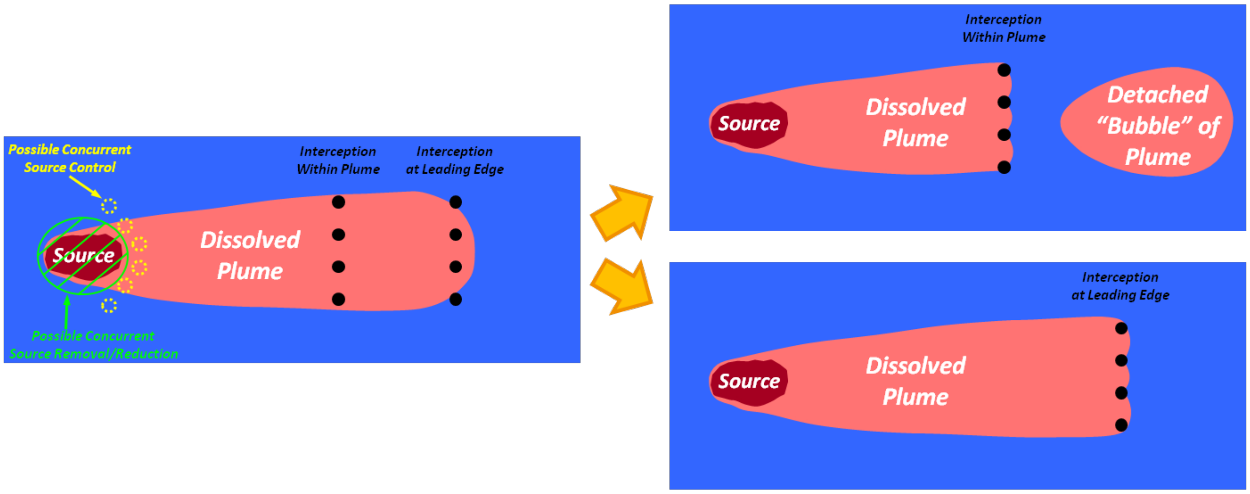

Figure 2. *Conceptual application of P&T for plume containment, showing (at right) intended outcomes for two examples of extraction well positioning. In the case where contamination is intercepted within the plume, a "bubble" of contamination remains downgradient from the P&T wells, which would be acceptable if the attenuation capacity can diminish concentrations to meet remedial goals. In the other case, contamination is intercepted at the distal end of the plume. Solid dots indicate extraction wells. Potential source area remediation is shown as the hatched zone covering the source area (for some source removal/reduction technology, such as excavation or thermal treatment) and dashed circles (for source control).*

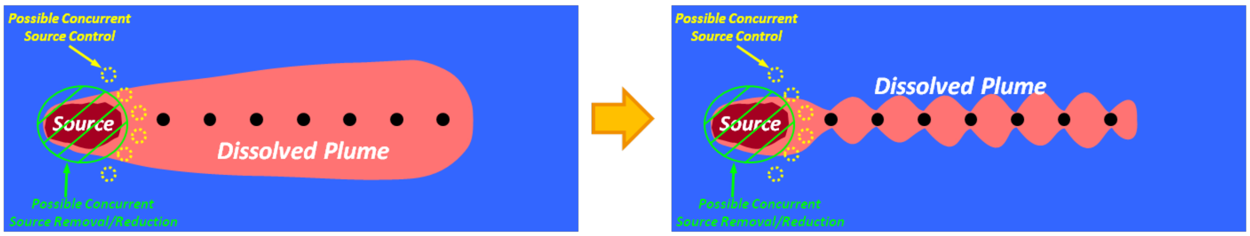

Figure 3. *Conceptual application of P&T for plume reduction, showing (at right) progress towards the intended outcome of volumetric treatment of the dissolved phase plume. In most cases it will be important to remove or contain the source for plume reduction to be successful. Solid dots indicate extraction wells (in one example layout). Potential source area remediation is shown as the hatched zone covering the source area (for some source removal/reduction technology, such as excavation or thermal treatment) and dashed circles (for source control).*

The performance and closure evaluation approach for P&T systems starts with gathering data and performing analyses to update the conceptual site model (CSM). The updated CSM provides a framework for understanding the characteristics of the subsurface (hydrogeology, flow, source, and plume), key metrics, and the P&T design. As part of considering optimization, transition, or closure of a P&T system, the original CSM developed for remedy selection and design should be revisited using available characterization, plume monitoring, and P&T operational data. An important aspect of updating the CSM is inclusion of historical trend data from the period of P&T remediation to help define the plume behavior and related conceptual model elements. Categories of data from the original CSM and updates from the remedy period include:

- a description of subsurface hydrogeology,
- a description of the groundwater flow field (with and without P&T in operation),
- general and quantitative depictions of the plume conditions,
- mass discharge estimates for key locations in the plume system (including the P&T system location[s]),
- an estimate for the plume attenuation capacity, and
- a description of the P&T design, operations, and historical performance.

The CSM information then needs to be used as a foundation for assessing P&T performance with respect to optimization, transition, or closure decisions. Key metrics for this assessment include the following items summarized below.

- Contaminant Concentrations
  - Comparison of the site contaminant concentrations to the identified remediation target concentrations and determining whether concentrations are increasing, stable, or decreasing is a key metric for the remedy decision because concentration goals are typically established in a Record of Decision (ROD). Concentrations typically establish a “bright line” of either being above or below a goal. Concentration trends relate to interpreting performance and predicting plume behavior in relation to supporting a decision.
- Contaminant Mass Discharge at the P&T System
  - For a pumping well or grouping of pumped wells, contaminant mass discharge (CMD) at the well is readily calculated from measured extraction flow rate and concentration data [8]. This CMD is a measure of the CMD in the aquifer within the capture zone of the well or well system. Thus, standard data collected for a P&T system can be translated into a measure of CMD in the captured portion of the aquifer. Using data collected over time, the changes in CMD over time can be determined. The P&T system CMD is a reasonable estimate of CMD in the aquifer within the capture zone. However, if the CMD is to be used for estimates of post-P&T plume behavior, then this CMD from the P&T system must be scaled based on the ratio of the groundwater flow through the capture zone during P&T operations to the flow under natural-gradient conditions. The CMD is important because it is a measure of either source strength or plume migration potential depending on where the P&T is located. The CMD is also important for evaluation in comparison to the attenuation capacity – a mitigating factor for source flux and plume migration potential.
- Attenuation Capacity
  - Attenuation capacity can be estimated using techniques to quantify the attenuation rate at portions of the contaminant plume/source upgradient and downgradient of the P&T system (e.g., [8, 9]). Single and multi-well attenuation rate analyses are a direct measurement suitable for many sites. Data on plume mass over time can be used to assess plume attenuation and may have advantages for non-standard plumes (e.g., plumes where the centerline changes with seasonal flow variations or for a detached plume). Mass flux (contaminant mass discharge) data from transects of monitoring wells perpendicular to the direction of flow and located at several distances along the axis of the plume can provide information on the stability of a plume (shrinking/expanding/stable), and plume attenuation (if care is applied to account for transport-related plume dynamics). Numerical modeling can also be used to compare observed plume dissipation downgradient of P&T (or at plume fringes for a P&T plume reduction application) to predicted responses with different levels of attenuation capacity included in the model. Attenuation capacity is important because it

describes the ability to mitigate plume size, concentrations, and transport. For sites where P&T has been applied, this information is needed to compare to the current CMD (a measure of source flux and plume migration potential) as a basic analysis for whether CMD has been decreased sufficiently by P&T that a revised remedy can consider a more significant role for attenuation processes and a decreased or terminated role for P&T.

- Plume Behavior and Time to Goal
  - Assessment of plume maps over time, coupled with predictive analysis of plume behavior, is an important set of information supporting decisions for future remedy approaches. Multiple tools are available for these analyses. Plume footprint would typically be a factor in P&T design and original performance goals and changes over time are important to evaluate performance and feed into predictions of post-P&T changes. These represent a volumetric measure that could be used to estimate the time to reach the remediation goal, in addition to the attenuation capacity estimates.
- P&T System Design, Performance, and Cost
  - Standard P&T design guidance provides methods for capture analysis (e.g., [7]) and these can be assessed in comparison to observed plume response. Operating information such as costs are also typically available and provide input to comparison with other potential remediation approaches.

To provide a structure for P&T performance assessment with these metrics, the approach defines categories of decision outcomes and then defines the technical data and information for each metric that are consistent with supporting a decision for each outcome. The site stakeholders can then compile information for each metric and use a weight-of-evidence evaluation based on these multiple metrics to develop the technical basis to support a decision for P&T optimization, transition, or closure. These metrics would be used in combination with additional site-specific information or conditions that are relevant to the decision to either adjust the weighting of the metrics or to include considerations other than those defined in the metrics. The goal of the assessment metrics is to provide a core of technical information to support the decision-makers in the remedy decision process. The defined categories of decision outcomes are:

- Initiate Remedy Closure
- Transition P&T to Monitored Natural Attenuation (MNA)
- Continue P&T
- Supplement P&T with Another Treatment Technology
- Transition from P&T to Another Treatment Remedy
- Transition P&T to Alternative Closure or Contamination Management Approach

The sections below summarize the type technical data and information for each metric that are consistent with supporting a decision for each outcome.

Initiate Remedy Closure

This outcome would normally be associated with reaching the remediation goals specified in a ROD. Demonstrating achievement of concentration goals typical in many RODs would consider recent guidance by the EPA (e.g., [10]). In most cases, only the contaminant concentration metric is applicable to supporting this decision outcome.

Transition P&T to MNA

A decision to terminate a P&T system and transition to a MNA remedy would be supported by the following conditions. While contaminant concentrations would still be above the goal, data should indicate that the concentration has declined over time. In addition, the CMD at the P&T system should have declined and be lower than the estimated attenuation capacity in the aquifer. Data and information should be available to document attenuation mechanisms. Estimates of plume behavior should predict that the plume will stabilize/decline and stay within an area where exposure pathways can be controlled over a reasonable time until goals are met, even though this MNA timeframe may be longer than the timeframe with continued P&T.

Continue P&T

An assessment may lead to a decision to continue the P&T remedy. In this situation, contaminant concentrations would still be above the goal, but data should indicate that the concentration has declined over time. The CMD at the P&T system should have declined and be expected to continue declining. However, the CMD will be higher than the estimated attenuation capacity in the aquifer. Attenuation mechanisms may be present but would not be expected to be sufficient as a remedy. Projections of plume behavior with P&T operating should indicate the ability to reach goals. Comparative analysis should indicate that continuation of the P&T system is more cost effective and has a reasonable remediation time compared to other viable remediation options.

Supplement P&T with Another Treatment Technology

Continued operation of the P&T system, but with application of a supplemental remedy (e.g., targeted source or plume treatment) would be supported by the following conditions. The contaminant concentrations would still be above the goal, but there may be only limited decline in concentrations and the P&T system CMD. However, the P&T would be performing an important function in control of the plume or hydraulic conditions that facilitates use of a supplemental technology to reduce concentrations and the CMD. Projections of plume behavior with P&T and a supplemental technology should indicate the ability to reach goals. Comparative analysis should indicate that the supplemented P&T approach is more cost effective and has a reasonable remediation time compared to other viable remediation options.

Transition from P&T to Another Treatment Remedy

The following site conditions would be supportive of transitioning from P&T to another treatment remedy. In this case, contaminant concentrations would still be above the goal, the CMD still above the attenuation capacity, and there may be only limited decline in concentrations and the P&T system CMD observed over time. Comparative analysis of remediation technologies would reveal that P&T has difficulty in meeting remediation goals, and that costs and performance are better for a new technology. It is important, however, to carefully evaluate the reasons for poor P&T performance and be reasonably confident that another technology will be successful [2, 11]. If site complexity is driving poor P&T performance and questions exist about performance of another technology, then transition to an alternative management approach (as described in the next outcome) should be considered.

Transition P&T to Alternative Closure or Contamination Management Approach

One outcome for a site may be related to its complexity and the associated difficulty in reaching remediation goals associated with unlimited use (e.g., drinking water standards), as has been discussed recently by the NRC [2] and the ITRC [11]. These sites would have contaminant concentrations that are still above the remediation goal, a CMD that is still above the attenuation capacity, and there may be only limited decline in concentrations and the P&T system CMD observed over time. Comparative analysis of remediation technologies would reveal that P&T and other technologies will have significant difficulty in meeting goals. Under these conditions, use of alternative approaches, such as discussed by the NRC [2] and the ITRC [11], should be considered.

CONCLUSIONS

The performance and closure evaluation approach for P&T systems described herein is still in development. The intent is to provide a structured approach for assessing P&T performance to support decisions about optimization, transition, or closure of a P&T remedy. The approach focuses on identifying data collection and analyses that will support decision makers in evaluating a P&T remedy. The process starts with gathering data and performing analyses to update the conceptual site model (CSM). Key metrics for evaluating appropriate endpoints include an assessment of the contaminant mass discharge and the attenuation capacity within the aquifer. While each site situation is different, the approach establishes a set of metrics that collectively can be used to distinguish between different decision outcomes that are best supported by the data and information from the site. This approach can help focus data collection and streamline the decision process by having the categories of decision outcomes and the decision metrics in mind at the onset of the process.

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ACKNOWLEDGEMENTS

This work was conducted as part of the Deep Vadose Zone−Applied Field Research Initiative at Pacific Northwest National Laboratory. Funding for this work was provided by the U.S. Department of Energy (DOE) Richland Operations Office. The Pacific Northwest National Laboratory is operated by Battelle Memorial Institute for the DOE under Contract DE-AC05-76RL01830.